

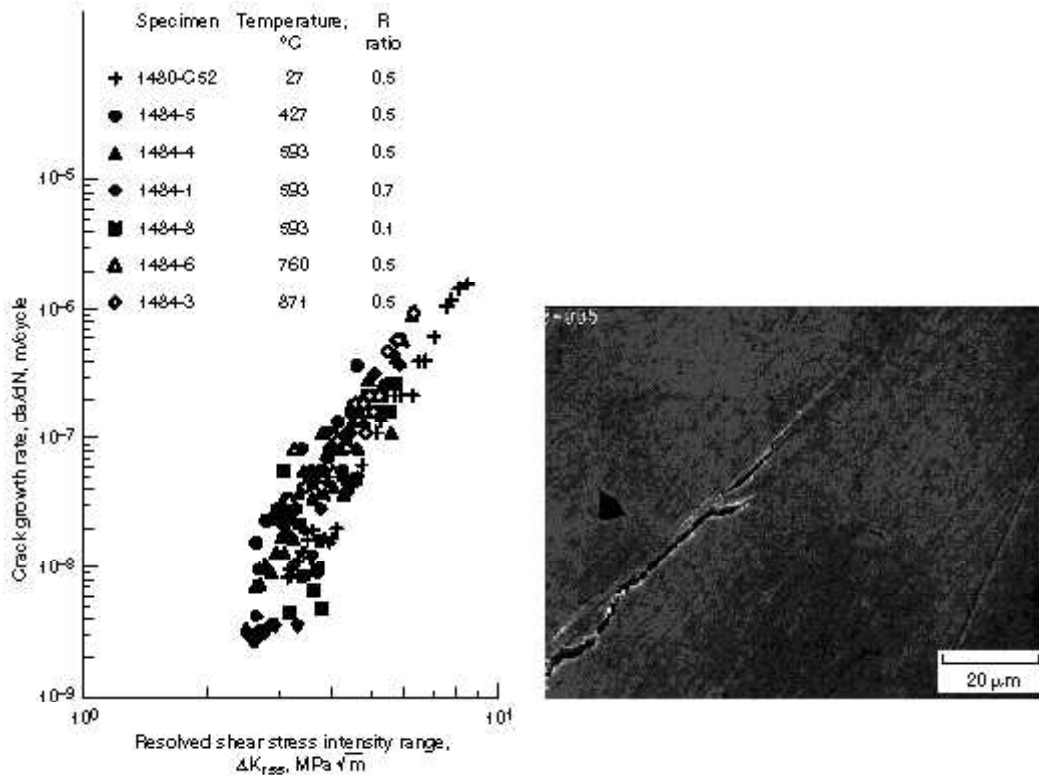
Methodology Developed for Modeling the Fatigue Crack Growth Behavior of Single-Crystal, Nickel-Base Superalloys

Because of their superior high-temperature properties, gas generator turbine airfoils made of single-crystal, nickel-base superalloys are fast becoming the standard equipment on today's advanced, high-performance aerospace engines. The increased temperature capabilities of these airfoils has allowed for a significant increase in the operating temperatures in turbine sections, resulting in superior propulsion performance and greater efficiencies. However, the previously developed methodologies for life-prediction models are based on experience with polycrystalline alloys and may not be applicable to single-crystal alloys under certain operating conditions. One of the main areas where behavior differences between single-crystal and polycrystalline alloys are readily apparent is subcritical fatigue crack growth (FCG). Whereas in polycrystalline alloys cracks grow perpendicular to the applied load (i.e., mode I cracks), in single-crystal alloys cracks often grow on the operative slip planes that are inclined to the applied load axis.

The NASA Lewis Research Center's work in this area enables accurate prediction of the subcritical fatigue crack growth behavior in single-crystal, nickel-based superalloys at elevated temperatures. Reference 1 describes the limitations of the currently used mode I crack-driving-force parameter and introduces two new parameters that are based on the resolved shear stresses on the individual slip systems present at the crack tip. The two parameters not only correlate the fatigue crack growth rates as a function of anisotropy but also are able to predict the operative slip system. These parameters can be utilized in life-prediction models, which, when developed, will give a more accurate estimate of the life of the component since they will be based on the actual deformation mechanisms by which progressive failure occurs.

The experimental part of the program was performed in a specially designed, high-temperature, in situ loading stage mounted inside a scanning electron microscope. This allowed for real-time observations of the operative failure modes at high magnifications. The identification of the ongoing failure mechanisms was instrumental in determining the conditions under which a given failure mode was active.

The influence of the environment on the fatigue crack growth behavior of the single-crystal alloy at elevated temperatures was also examined. We determined that oxygen embrittlement at sufficiently low frequencies and high temperatures is responsible for a transition from an octahedral crack growth on the slip planes to the mode I crack growth so prevalent in polycrystalline alloys.



Left: Octahedral fatigue crack growth data plotted in terms of the delta K_{rss} parameter at various temperatures and R ratios. Right: Octahedral mode crack growth process at 427 °C.

Reference

1. Telesman, J.; and Ghosn, L.: Fatigue Crack Growth Behavior of a PWA 1484 Single Crystal Superalloy at Elevated Temperatures. ASME Paper 95-GT-452, 1995.